Multiple Access Using Different Codes Lengths
For Global Navigation Satellite Systems

Field of the invention

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The invention relates to a method for determining a delay of
a spread data symbol stream, comprising the steps of at
least partially correlating a signal, which comprises at
least first and second spread data symbol streams that are
10 obtained by spreading at least a first and second data
symbol stream with a respective first and second code, with
said first code to obtain at least two portions of a Cross-
Correlation Function (CCF) between said signal and said
first code, and combining said at least two portions of said
15 CCF to obtain a combined CCF portion from which a first
delay of said first spread data symbol stream is determined.

Background of the invention

20 In Global Navigation Satellite Systems (GNSS) such as for
instance the Global Positioning System (GPS) or the upcoming
European Galileo system, a receiver uses triangulation based
on the distance to at least three satellites and
plausibility considerations to determine its position. For
25 the triangulation, at first the position of the satellites
has to be known to the receiver. This information is stored
in each receiver. Furthermore, the distance to a satellite
has to be determined from the propagation delay of a signal
that is emitted by said satellite and subsequently received
30 at said receiver. In the Global Positioning System (GPS),
this is achieved by correlation of a spread data symbol
stream that has been transmitted by a satellite and received
by a receiver with a replica of the code with which the
spread data symbol stream has been spread. In the GPS, said

data symbol stream corresponds to a navigation message,
which has a bit rate of 50 bps, and the code is a
Coarse/Acquisition (C/A) code, which is a Gold code
appearing like a pseudo-random-noise (PRN) code with a chip

5   rate of 1.023 MHz and a length of 1023 chips, wherein a chip
is an element of the set $\{0,1\}$ similar to a bit, but is not
representing actual data. The duration of a chip is denoted
as T_c.

10   Basically, the spreading operation is performed by modulo-2
addition of the high-chip-rate C/A code and the low bit rate
navigation message, so that each bit of the navigation
message is modulo-2 added with 20 repetitions of the C/A
code of length 1023 chips or duration T = 1 ms each.

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The GPS navigation message, or, more general, a data stream
composed of several data symbols, thus is spread with a
code, obtaining a spread data symbol stream, wherein the
term spreading refers to the spreading of the frequency

20   bandwidth of the data symbol stream that is increased by a
factor that equals the ratio of code chip rate and data
symbol rate, which, in the above-mentioned GPS example,
equals 20460.

25   In Fig. 1, said spread data symbol stream 100 is depicted as
being composed of two portions 100-1 and 100-2, each
corresponding to the duration T of the code. The spread data
symbol stream 100 is depicted in discrete-time form, wherein
Binary Phase Shift Keying (BPSK) is exemplarily assumed as

30   the modulation technique, so that the symbol alphabet of the
spread data symbols is $\{-1,1\}$. The spread data symbol stream
is transmitted by a satellite and received as received
spread data symbol stream 101 at a receiver. The step of
modulating and demodulating the spread data streams is

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omitted here for ease of presentation. The received spread data symbol stream 101, also in discrete-time form, basically equals the transmitted spread data symbol stream, apart from a propagation delay τ_1. For the scenario of Fig. 1, it was assumed that the Signal-to-Noise Ratio (SNR) at the receiver is large enough and that channel distortions of the propagation channel such as attenuation, phase shift, Doppler shift and multi-path propagation have been compensated, for instance by means of amplification and equalization, so that the chips in both portions 101-1 and 101-2 of the received spread data symbol stream equal the respective chips in the respective portions 100-1 and 100-2 of the transmitted spread data symbol stream 100, apart from the propagation delay τ_1.

At the receiver, the time instance at which the transmitter is starting the transmission of said transmitted spread data symbol stream 100 is known, and at the same time instance, the receiver generates a replica 102 of the code that is used to spread the data symbol stream in the transmitter. This requires the clocks in both the transmitter and receiver to be synchronized. Synchronization of the receiver clock is accomplished by processing the receive signals of at least four satellites, wherein the satellites use high-precision atomic clocks to fix a so-called universal time.

The receiver then computes the Cross-Correlation Function (CCF) 103 between the received spread data symbol stream 101 and the locally generated code replica 102. The CCF for two discrete-time functions $f(n{\cdot}T_c)$ and $g(n{\cdot}T_c)$ is defined as

$$\varphi_{fg}(m \cdot T_c) = \frac{1}{L} \cdot \sum_{n=0}^{L-1} f(n \cdot T_c) \cdot g((n+m) \cdot T_c),$$

wherein L denotes the length of the summation interval.

For the scenario of Fig. 1, the Auto-Correlation Function
5   (ACF) $\varphi_{cc}(m \cdot T_c)$ of the discrete-time code $c(n \cdot T_c)$ 102 is
defined as:

$$\varphi_{cc}(m \cdot T_c) = 1 \qquad \text{if } m = 0;$$
$$|\varphi_{cc}(m \cdot T_c)| \leq \Delta \quad \text{with } 0 \leq \Delta << 1 \quad \text{if } m \neq 0$$

10 i.e., it has an auto-correlation peak at m=0 and small
values elsewhere.

With the received spread data symbol stream 101 in Fig. 1
consisting of two portions 101-1 and 101-2 that are shifted
15 versions of the respective portions 100-1 and 100-2 of the
transmitted spread data symbol stream, which in turn
represent the spreading of a data symbol with the code of
length T, respectively, wherein the respective data symbols
of both portions 100-1 and 100-2 are assumed to be equal,
20 the CCF 103 simply contains two times the ACFs $\varphi_{cc}(m \cdot T_c)$ of
the code $c(n \cdot T_c)$, weighted with the respective data symbol,
wherein said first weighted ACF 103a-1 $\varphi_{cc}(m \cdot T_c)$ of the code
is shifted by the delay τ_1 of the received spread data
symbol stream 101 and the second weighted ACF 103a-2 is
25 shifted by τ_1 + T. If further portions 100-3, 100-4 etc.
followed the two depicted portions of the transmitted spread
data symbol stream 100 (and corresponding portions 101-3,
101-4, etc. in the received spread data symbol stream), the
CCF would show further weighted ACFs , each separated from
30 the preceding ACF by a duration of T. The CCF thus is
periodic in T.

Apparently, from the CCF, the propagation delay τ_1, which is indicative of the distance between the transmitter and the receiver, can be determined from the position of the auto-correlation peak 103a-1.

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The scenario as described in Fig. 1 assumed that the SNR at the receiver was high enough so that the received spread data symbol stream 101 equals a shifted version of the transmitted spread data symbol stream 100. However, at

10 operating points where GNSS receivers are normally deployed, the SNR may be smaller, so that the received spread data symbol stream 101 does no longer equal the delayed transmitted spread data symbol stream 100, for instance some of the chips within the received spread data symbol stream

15 101 may be changed by an additive noise process in a way that they more resemble a different BPSK symbol. Furthermore, the received spread data symbol stream may become complex-valued due to the fact that both the amplitude and phase of its chips are altered by noise and

20 channel distortion. Due to the random characteristics of the propagation channel and the noise process that adds to the received signal at the receiver, the errors in the spread data symbol stream 101 are different in different portions 101-1 and 101-2 of the received spread data symbol streams.

25 The CCF 103 then no longer consists of the periodically repeated weighted ACF of the code, but may contain further small peaks at time instances different from the actual auto-correlation peaks at $\tau_1+i\cdot T$, where is an integer with $i=0,1,..$. Furthermore, the amplitude of said auto-

30 correlation peaks may be smaller.

To combat this effect, which aggravates the proper detection of the propagation delay τ_1, combining at least two

corresponding portions 103-1 and 103-2 of the CCF 103 can be performed. It is the aim of the combining procedure to reduce the effect of the random distortions in the ACFs of the codes within the CCF 103 and to obtain a combined CCF

5 that allows for a more precise and robust determination of the propagation delay τ_1. For instance, the portion 103-1 of the CCF 103 from time instance $\tau = 0$ to time instance $\tau = T$ and the portion 103-2 of the CCF 103 from time instance $\tau = T$ to time instance $\tau = 2T$ may be combined by integration or

10 averaging. When integration (or summing) is used, the values of corresponding time instances of the different CCF portions 103-1, 103-2 are integrated to obtain an integrated value for each of said time instances, which then represent an integrated CCF portion. Due to the periodic character of

15 the ACF peaks 103a-1 and 103a-2, i.e. the fact that the ACF peaks are always located at the same time instance within a portion 103-1, 103-2 of the CCF 103, the ACF peaks then are steadily enhanced during the integration, whereas the distortions, due to their random occurrence at different

20 time instances, are not enhanced to the same degree as the ACFs. Consequently, the combined CCF portion has an increased sensitivity than the single CCF portions 103-1, 103-2 and the desired propagation delay τ_1 is more securely detected from the position of the enhanced ACF peak in the

25 combined CCF portion.

As already mentioned, the distances to at least three satellites are required in a GNSS system to accomplish triangulation. To this end, the transmitted spread data

30 symbol streams of at least three satellites are received, as depicted in Fig. 2.

Fig. 2 depicts the reception of first, second and third received spread data symbol streams 200, 201 and 202, which are delayed with respective propagation delays τ_1, τ_2 and τ_3. Each received spread data symbol stream 200, 201 and 202 has

5 been generated from respective first, second and third data symbol streams by spreading with a respective first, second and third code, transmitted by a respective satellite and delayed by a respective propagation delay τ_1, τ_2 and τ_3 due to the different distances between the transmitting satellites

10 and the receiver. In contrast to the illustration in Fig. 2, the receiver does not separately receive said spread data symbol streams 200, 201 and 202, but only receives a signal that is a superposition of said three spread data symbol streams 200, 201 and 202.

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The receiver then correlates the received signal with replicas of codes that are used by each transmitting satellite, respectively. In Fig. 2, exemplarily the generation of a replica 203 of the first code that is used

20 by the satellite that transmitted the first spread data symbol stream and the correlation of this first code replica with the received signal is depicted. The resulting cross-correlation function 204 now does not only contain the periodically repeated weighted ACFs 204a-1 and 204a-2 of the

25 first code, but also periodically repeated CCFs 204b-1 and 204b-2 between the first and second code and periodically repeated CCFs 204c-1 and 204c-2 between the first and third code, each weighted with the respective data symbols of the second data symbol stream and the third data symbol stream.

30 The CCF 204 between the receive signal that comprises the first, second and third received spread data symbol streams and the replica 203 of the first code thus still is periodic in T, wherein T is the length of the first, second and third

code, but the detection of the desired delay τ_1 is aggravated in particular if the amplitudes of the CCFs 204b and 204c within the CCF 204 approach the amplitudes of the ACFs 204a. Note that, whereas random distortions in the

5 received spread data symbol streams that stem from noise may be reduced by averaging over several portions 204-1, 204-2 of the CCF 204 as explained above, the influence of the CCFs 204b and 204c are of systematic character and can not be averaged out of the CCF 204.

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When designing the GNSS, it is thus advantageous to select codes for the different satellites that have high auto-correlation peaks and low cross-correlation peaks, so that the delays τ can be securely detected.

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The above-mentioned properties of the codes can be approached by increasing the length of the codes. However, increasing the length of the codes generally slows down the acquisition time and vastly increases the computational

20 complexity of the receiver and thus its costs.

A different approach to reduce the cross-correlation uses scrambling codes that comprise significantly more chips than the spreading codes in addition to the scrambling codes.

25 However, as it is the case with increased lengths of the spreading codes, the computational complexity of the receiver increases when scrambling is used.

Summary of the invention

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In view of this problem, it is thus an object of the present invention to improve the determination of a delay of a spread data symbol stream.

It is proposed that a method for determining a delay of a
spread data symbol stream comprises the steps of at least
partially correlating a signal, which comprises at least

5   first and second spread data symbol streams that are
obtained by spreading at least a first and second data
symbol stream with a respective first and second code, with
said first code to obtain at least two portions of a Cross-
Correlation Function (CCF) between said signal and said

10   first code, and combining said at least two portions of said
CCF to obtain a combined CCF portion from which a first
delay of said first spread data symbol stream is determined,
wherein said first code and said second code are composed of
chips and wherein the number of chips of said first code is

15   different from the number of chips of said second code.

Said method may for instance be used in a GNSS system to
determine the distance between satellite transmitters and a
receiver based on determined propagation delays, or in a

20   communication system with Code Division Multiple Access
(CDMA) as medium access technique to achieve coarse
synchronization. Said at least first and second data symbol
streams may for instance be bit streams with a respective
first and second bit rate, which may be spread with

25   respective first and second codes that are composed of
respective numbers of chips (belonging to a chip alphabet
$\{0,1\}$) and may be characterized by a respective first and
second chip rate. Spreading may be performed by chip-by-chip
modulo-2 addition of the chips of said respective first and

30   second code to the bits of the respective first and second
data symbol streams, yielding respective first and second
spread data symbol streams that may also be characterized by
a first and second chip rate. Said first and second spread
data symbol streams then may be mapped to modulation symbols

such as for instance Binary Phase Shift Keying (BPSK)
symbols belonging to the alphabet {-1,1}. Alternatively,
said spread data symbol streams may be further processed
without modulation.

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Said at least first and second data symbol streams may
equally well be modulation symbols that correspond to the
bits of a bit stream, for instance Binary Phase Shift Keying
(BPSK) symbols or Quaternary Phase Shift Keying (QPSK)
10   symbols, and said at least first and second data symbol
streams may then be spread with said first and second codes
(with chips belonging to the alphabet {-1,1}) by chip-by-
chip multiplication of the chips of the respective codes
with the data symbols of said respective first and second
15   data symbol streams, yielding respective first and second
spread data symbol streams. Said first and second data
symbol streams may then be pulse-shaped, modulated with a
carrier frequency and transmitted by a transmitter. At a
receiver, a signal may be received that is a superposition
20   of delayed versions of said transmitted spread data symbol
streams, wherein said respective delays stem from the
traveling distance between the respective transmitter and
the receiver and may be counted from a respective time
instance, at which a transmission of a respective spread
25   data symbol stream has started. Said respective time
instances at which said respective transmissions are started
may all coincide due to the use of a universal time for all
transmitters. In addition to the respective delays, said
transmitted spread data symbol streams contained in said
30   signal may be attenuated and corrupted by noise.
Transmission may take place via a wired or a wireless
connection. At the receiver, said signal may be amplified,
demodulated (only if they were modulated at the transmitter)
and sampled. Furthermore, equalization may be performed to

combat the distortions of the propagation channel between transmitter and receiver. Said signal is correlated with said first code, a replica of which may be generated by said receiver, wherein said correlation may be performed in

5 discrete or continuous time, yielding either a discrete-time CCF or a continuous-time CCF. Said replica of said first code may be synchronized with the time instance at which the transmission of said first spread data symbol stream was started. Said correlation may be performed for the entire

10 signal, or partially, i.e. only for selected portions of the signal. Correspondingly, then either the complete CCF between the signal and the code is obtained, or only portions of said CCF are obtained. At least two portions of said CCF are then combined. If the complete CCF is

15 calculated, portions of said CCF may have to be selected prior to combination. If said CCF has only been calculated partially, either the calculated portions or a selection of portions of said calculated portions may be combined. Said combination enhances the sensitivity of the combined CCF

20 portion in comparison to the sensitivity of the CCF, so that a first delay can be detected from said combined CCF portion in a more robust and accurate way than it is possible from the CCF. Combination may comprise averaging or integration, times series analysis or statistical processing of the

25 portions of the CCF.

The number of chips of said first code is advantageously chosen different from the number of chips of said second code, so that dominant cross-correlation peaks (that stem

30 from the cross-correlation between said first and second code) in said at least two portions of said CCF that are combined do not appear at corresponding positions within said at least two portions of said CCF and are thus not enhanced when said at least two portions of said CCF are

combined. In contrast, auto-correlation peaks (that stem from the auto-correlation of said first code) appear at corresponding positions within said at least two portions of said CCF and are thus enhanced by the combining. From the

5   position of the enhanced auto-correlation peaks within the combined CCF portion, the first delay can be determined. The use of different numbers of chips within said first and second code leads to different spreading gains at the receiver, when the received spread data symbols are de-

10   spread. The relative difference in spreading gain between codes is insignificant for large numbers of chips in each code and only small differences between the numbers of chips in each code. Due to the different numbers of chips in the spreading codes, the method of the present invention may be

15   specified as a Vary Length Code Division Multiple Access (VL-CDMA) method in contrast to the state-of-the-art CDMA methods that apply equal spreading code lengths for all codes.

20   According to the method of the present invention, it may be preferred that said step of combining said at least two portions of said CCF comprises the step of averaging said at least two portions of said CCF or integrating said at least two portions of said CCF. When averaging said at least two

25   portions of said CCF, the average is taken over the values at corresponding positions in said at least two portions of said CCF, for instance, the first value in each portion is averaged to yield a first average value which represents the first value of the combined CCF portion, then the second

30   value in each portion is averaged to yield a second averaged value, and so forth. Similar, when integration is performed, the respective first values in each portion may be summed to obtain a first value of the combined CCF portion, and so forth. Before averaging or integrating the portions, the

absolute value of the values in each portion may be taken. Both averaging and integrating may be performed coherently or non-coherently and both in discrete or continuous time.

5 According to the method of the present invention, it may be preferred that the number of chips of said first code and the number of chips of said second code are not multiples of each other.

10 According to the method of the present invention, it may be preferred that the chip rates of said at least first and second spread data symbol streams are equal. The data symbol rates of said at least first and second data symbol streams may be different, and due to the use of first and second
15 code with respective different numbers of chips, but with the same chip rate each, the respective chip rates of the respective first and second spread data symbol stream may be made equal. As the chip rate of the code, which is defined as the reciprocal value of the chip duration, the chip rate
20 of the spread data symbol stream is also defined as the reciprocal value of the chip duration. The spreading operation does not change the duration of a chip.

According to the method of the present invention, it may be
25 preferred that N chips of said at least first and second spread data symbol stream are contained in a frame, respectively, and wherein N is the least common multiple of the number of chips of said first code and the number of chips of said second code. Selecting the lengths of the
30 codes in a way that said at least first and second spread data symbol streams can be organized in frames that comprise the same number of chips allows for frame synchronization between said at least first and second spread data symbol streams.

According to the method of the present invention, it may be preferred that said first code and second code are software codes and/or pseudo-random-noise codes. Said codes may for

5   instance be systematically generated, such as for instance Gold codes, or randomly generated. In both cases, the codes may appear like random noise, they may for instance be zero-mean.

10   According to the method of the present invention, it may be preferred that said first code and second code are taken from the same basic code and only differ in the number of chips. Said first and second codes are then obtained from said basic code by simple copying, for instance the first

15   code copies the first 1023 chips, and the second code copies the first 1022 chips from said basic code. The method then can be considered as an independent medium access technique (Vary Length Multiple Access, VLMA), because concurrent access to a shared transmission medium is not achieved by

20   assigning pseudo-orthogonal codes to each transmitter, but by assigning each transmitter the same code and only varying the length of each transmitters code to some extent. It is advantageous in VLMA to combine at least two portions of said CCF in order to enhance the auto-correlation peaks and

25   to reduce the impact of cross-correlation peaks that quite naturally arise because all assigned codes are basically equal.

According to the method of the present invention, it may be
30   preferred that said signal further comprises a third spread data symbol stream that is obtained by spreading a third data symbol stream with a third code, wherein said third code is composed of chips and wherein the number of chips of said third code is equal to the number of chips of said

first code or to the number of chips of said second code. It is thus not required that each data symbol stream is spread with a code that has a different length compared to the length of the codes with which the other data symbol streams

5 are spread. Two codes may thus have the same length, a principle that may be denoted as "code length reuse". It may be preferred that the codes that have the same length are not separated via VLMA, i.e. are not copied from the same basic code.

10

According to the method of the present invention, it may be preferred that said first and second code are time-invariant. Then for the transmission of all spread data symbol streams, always the same first and second codes are

15 used, i.e. the sequence of chips within each code and the length of each code does not change. This omits the required amount of signaling encountered when codes would be changed.

According to the method of the present invention, it may be

20 preferred that said first and second code are changed in certain intervals. It may be advantageous to change the sequence of chips within each code or the length of each code between subsequent transmissions of spread data symbol streams, i.e. there may exist spread data symbol streams

25 originating from one transmitter that have been spread with different codes. This technique represents a powerful means against jamming.

According to the method of the present invention, it may be

30 preferred that said first and second code are periodically changed so that the average number of chips in said respective first and second code is equal. When the chip rate of all codes is equal, but at least two codes have different numbers of chips, at least the two data symbol

streams that are spread with the at least two codes that have different numbers of chips have to have different data symbol rates. If on the average, constant data symbol rates are desired for all data symbol streams, the codes

5   themselves or only the length of the codes may be periodically changed at least for the two data streams that have different data symbol rates. E.g. for the transmission of a first data symbol stream, a first code of 1023 chips is used for a limited time, and then a code of 1022 chips is

10   used for a further limited time. Concurrently, for the transmission of a second data symbol stream, a second code of 1022 chips is used for said limited time, and then a code of 1023 chips is used for said further limited time. Then the average symbol rates of both data symbol streams is

15   equal, although in both limited time periods, different code lengths have been used. This concept may be denoted as "code length hopping". In effect, then the chip rate and the average data symbol rate of all spread data symbol streams is equal, which is highly desirable.

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According to the method of the present invention, it may be preferred that said signal is a receive signal comprising the superposed spread data symbol streams that have been transmitted by satellite transmitters and received at a

25   receiver with respective propagation delays, and wherein said propagation delays are indicative of the distance between said receiver and said respective satellite transmitters. Said satellites may transmit navigation messages of low bit rate that indicate correction

30   information, for instance correction information concerning the ephemeris of the satellite or the propagation model, which are spread with a C/A code of higher chip rate. The spread navigation messages are then transmitted by the satellite, propagate through the channel between the

satellite and a receiver and are accordingly delayed. Said delay is basically proportional to the distance between the satellite and the receiver, apart from non-linear influences of the propagation channel. From the estimation of distances

5   to at least three satellites, the receiver is enabled to determine its position via triangulation, the distance towards a fourth satellite may be required to synchronize the local clock of the receiver to the universal time of the satellites.

10

According to the method of the present invention, it may be preferred that said satellite transmitters are satellite transmitters of a Global Navigation Satellite System (GNSS). Said system may for instance be the Global Positioning

15   System (GPS) or the European Galileo system.

It is proposed that a computer program comprises instructions operable to cause a processor to perform the above mentioned method steps. Said computer program may be

20   loaded into the internal memory of a processor that is integrated in a receiver.

It is proposed that a computer program product comprises a computer program with instructions operable to cause a

25   processor to perform the above-mentioned method steps.

It is proposed that a device for determining a delay of a spread data symbol stream comprises means for at least partially correlating a signal, which comprises at least

30   first and second spread data symbol streams that are obtained by spreading at least a first and second data symbol stream with a respective first and second code, with said first code to obtain at least two portions of a Cross-Correlation Function (CCF) between said signal and said

first code, and means for combining said at least two portions of said CCF to obtain a combined CCF portion, from which a first delay of said first spread data symbol stream is determined, wherein said first code and said second code

5   are composed of chips and wherein the number of chips of said first code is different from the number of chips of said second code. Said device may be part of a GNSS receiver or may be part of a control station that performs the determination of the delay and offers said delay information

10 to GNSS receivers or the satellites themselves.

It is proposed that a system comprises at least a first and a second transmitter, which transmit respective first and second spread data symbol streams that are obtained by

15 spreading at least a respective first and second data symbol stream with a respective first and second code, wherein said first code and said second code are composed of chips and wherein the number of chips of said first code is different from the number of chips of said second code, and at least

20 one receiver, wherein said receiver receives a signal comprising at least said respective first and second spread data symbol streams, wherein said receiver at least partially correlates said signal with said first code to obtain at least two portions of a Cross-Correlation Function

25 (CCF) between said signal and said first code, and wherein said receiver combines said at least two portions of said CCF to obtain a combined CCF portion, from which a delay of said first spread data symbol stream is determined.

30 Brief description of the figures

These and other aspects of the invention will be apparent from and elucidated with reference to the embodiments described hereinafter. In the figures show:

Fig. 1:   a schematic illustration of the synthesis of a
            Cross-Correlation Function (CCF) in a single-
            transmitter GNSS system according to the prior
5   art;

Fig. 2:   a schematic illustration of the synthesis of a
            Cross-Correlation Function (CCF) in a multi-
            transmitter GNSS system according to the prior
10   art;

Fig. 3:   a schematic illustration of the synthesis of a
            Cross-Correlation Function (CCF) in a multi-
            transmitter GNSS system according to the present
15   invention;

Fig. 4:   an illustration of the process of combining
            portions of a CCF into a combined CCF portion
            according to the present invention;
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Fig. 5:   an illustration of the process of combining
            portions of a CCF into a combined CCF portion
            according to the Vary Length Multiple Access
            (VLMA) technique according to the present
25   invention;

Fig. 6:   a comparison of the achievable reduction of the
            cross-correlation as a function of the code
            length according to the prior art and according
30   to different parameterizations of the present
            invention;

Fig. 7:   a flow chart depicting the relevant method steps
            of the present invention; and

Fig. 8:   a schematic illustration of a device according
            to the present invention.

5   Detailed description of the invention
     Fig. 3 schematically illustrates the synthesis of a Cross-
     Correlation Function (CCF) in a multi-transmitter GNSS
     system according to the present invention. The first row of
     Fig. 3 shows a first received Spread Data Symbol Stream
10   (SDSS) 300 that basically represents a delayed version of a
     first transmitted SDSS. Said first transmitted SDSS 300 is
     obtained by spreading a data symbol stream with a first code
     302. In the first row of Fig. 3, only three repetitions of
     the code 302 of duration T each are depicted, wherein it is
15   assumed that each repetition of the code spreads one data
     symbol. BPSK modulation is assumed, so that the symbol
     alphabet of the SDSS is {-1,1}. However, modulation is not
     mandatory. The SDSS then may be subject to pulse shaping and
     modulation on a carrier frequency, such as for instance the
20   L1 carrier of a GPS system, and then is transmitted to a
     receiver over a channel that causes a first propagation
     delay τ_1. Similarly, a second SDSS is transmitted by a second
     transmitter and delayed by a second delay τ_2, as shown in the
     second row of Fig. 3.
25
     However, in contrast to the scenario of Fig. 2, the number
     of chips of the first code that is used to spread the first
     data symbol stream is different from the number of chips of
     the second code that is used to spread the second data
30   symbol stream, as can be seen from the comparison of the
     first and second row of Fig. 3. The first code has a length
     of T and comprises 16 chips, wherein the second code has a
     length of $T' = \frac{3}{4} T$ and comprises only 12 chips. The chip rate

of both codes equals the reciprocal value of the chip
duration T_c and is equal for both the first and second code.
However, to allow for frame synchronization between the
frames of the first and second transmitter, the number of
5   chips of the first and second code were chosen so that the
number of chips per frame is the least common multiple of
the number of chips of the first and second code. In the
present example, a frame comprises 64 chips, corresponding
to three repetitions of the first code of length 16 chips
10   and four repetitions of the second code of length 12 chips.
Correspondingly, three data symbols of the first data symbol
stream are contained in said frame, whereas four data
symbols of the second data symbol stream are contained said
frame. The data symbol rate of said first data symbol stream
15   is thus by a factor ¾ smaller than the data symbol rate of
the second data symbol stream.

At the receiver, said two received SDSS 300, 301 as depicted
in the first and second row of Fig. 3 contribute to one
20   receive signal that may be demodulated (if they were
modulated before), filtered with a pulse-shape matched
filter and sampled at the receiver. Furthermore, signal
amplification and equalization may be performed to combat
the attenuation and distortion of the channel. Said receive
25   signal is correlated with a replica of said first code 302
as shown in the third row of Fig. 3. The code replica 302 is
generated by the receiver at a time instance at which the
first transmitter is known to transmit the first SDSS. Said
correlation produces the CCF 303 as depicted in the
30   lowermost row of Fig. 3. As in Figs. 1 and 2, this CCF is to
be understood in an illustrative way and does not represent
the actually calculated CCF. The auto-correlation peaks
303a-1,..,303a-3 of the first code 302, stemming from the
correlation of the first code 302 with the first received

SDSS 300, are the same as in Fig. 2, i.e. occur at $\tau_1 + i \cdot T$, with $i=0,..,2$. However, the cross-correlation peaks 303b-1,..,303b-4 appear periodically, but now with a period of $T'=\frac{3}{4} T$ (this is at least true when disregarding transient

5   effects of the CCF 303). The effect of the change of this period T' of the cross-correlation peaks, as compared to the period T of the cross-correlation peaks in Fig. 2, is that when now portions 303-1, 303-2 of the CCF 303, for instance the portion 303-1 of the CCF 303 starting at time instance

10    $\tau=0$ to time instance $\tau=T$ and the portion 303-2 of the CCF 303 starting at time instance $\tau=T$ to time instance $\tau=2T$ are combined by integration, the relative position of the auto-correlation peak 303a-1 in the first portion and the relative position of the auto-correlation peak 303a-2 in the

15   second portion is the same, i.e. both auto-correlation peaks are to be found at a distance τ_1 from the left border of the respective portion 303-1, 303-2, so that the amplitude of the auto-correlation peak is effectively doubled when integrating said both portions 303-1, 303-2 of the CCF 303.

20   However, the relative position of the cross-correlation peak 303b-1 within the first portion 303-1 and the relative positions of the cross-correlation peaks 303b-2 and 303b-3 within the second portion 303-2 of the CCF 303 are not the same, so that when integrating both portions 303-1, 303-2 of

25   the CCF 303, the cross-correlation peaks are not enhanced. Thus by integration of said two portions of the CCF 303 in combination with the use of different numbers of chips in the first and second code, which causes the auto-correlation peaks and the cross-correlation peaks within the CCF 303 to

30   have different periods, the ratio between the amplitude of the auto-correlation peak to the maximum amplitude that is achieved by any of the correlation peaks is vastly increased, which may be interpreted as an increase in the

signal-to-interference ratio. This increased signal-to-interference ratio allows for a more robust and precise determination of the propagation delay τ_1 from the combined CCF portion.

5

Fig. 4 is an illustration of the process of combining different portions S1, S2 and S3 of a CCF into a combined CCF according to the present invention. In the first three rows of figure 4, a respective portion S1, S2

10 and S3 of a CCF similar to the portions of the CCF 303 in the last row of Fig. 3 is depicted, respectively, wherein the CCF in Fig. 4 is computed between a receive signal that comprises the received SDSSs of a first and a second transmitter, and a first code, wherein said first code is

15 used by the first transmitter and comprises $N_1=64$ chips, and wherein the second code is used by the second transmitter and comprises $N_2=62$ chips. The solid line 400 represents the auto-correlation peaks, and the dashed line 401 represents the cross-correlation peaks.

20

As can be seen from the first three rows of Fig. 4, the auto-correlation peaks 400 remain at their positions within the portions of the CCF, whereas the cross-correlation peaks 401 are moving due to the different number of chips in the

25 first and second code.

The last row of Fig. 4 shows the combined CCF portion that is yield by integrating the CCF portions S1, S2 and S3 in the three rows above, whereas the ordinate scale in the last

30 row of Fig. 4 is different as compared to the three rows above: Apparently, the auto-correlation peaks 400 have been enhanced, whereas the cross-correlation peaks 401 are barely visible in the changed scale.

Fig. 5 is an illustration of the process of combining

portions S1-S4 of a CCF into a combined CCF according to the

Vary Length Multiple Access (VLMA) technique according to

5   the present invention. A first transmitter uses a first code

of length $N_1=64$ chips, and a second transmitter uses exactly

the same code, but with the last two chips cut off, so that

the second code only comprises $N_2=62$ chips. A portion S1

from the CCF between the receive signal and the first code

10   is depicted in the left column of Fig. 5, whereas a portion

S1 from a CCF between the same receive signal and the second

code is depicted in the right column of Fig. 5. In the left

column plots, the auto-correlation peaks 500 are given in

solid lines and the cross-correlation peaks 501 are given in

15   dashed lines, whereas in the right column, the auto-

correlation peaks 502 are given in dashed lines and the

cross-correlation peaks 503 are given in solid lines. The

second row of Fig. 5 shows the respective results of

integrating over two portions S1 and S2 of the respective

20   CCFs, the third row shows the result of the integration over

three portions S1-S3 of the respective CCF, and so forth.

As can be spotted from the first row of Fig. 5, when only

considering one portion of the CCF and using merely the same

25   code for both transmitters according to the VLMA principle,

the auto-correlation peaks and the cross-correlation peaks

reach approximately the same amplitudes. Proper detection of

a transmission delay, or, as it is desired in VLMA,

separation of the data symbol streams of two transmitters,

30   is not possible. However, as can be seen from the second to

the fourth row of Fig. 5, with increasing numbers of

portions of the CCFs that are integrated, the amplitudes of

the respective cross-correlation peaks decrease as compared

to the amplitudes of the auto-correlation peaks. After only

two integrations, cf. the second row of Fig. 5, already proper detection of the first and second propagation delays and separation of the signals data symbol streams of the first and second transmitter is possible.

5

Fig. 6 presents a comparison of the achievable reduction of the cross-correlation in dB as function of the code length N according to the prior art and according to different parameterizations of the present invention.

10

The curve 600 represents a state-of-the-art CDMA system with pseudo-random spreading codes of length N, wherein the codes of both transmitters have the same length. Curve 601 represents a system according to the present invention with

15 a first code of length N and a second code of length N-1, wherein 5 different portions of the CCF are integrated. For curves 602 and 603, 10 and 20 integrations have been performed, respectively.

20 It can be readily seen that performance improves from curves 600 to 603. In particular, as can be seen when comparing the operating points A (-19.3 dB) and B (-29.9 dB), a gain of $10 \cdot \log_{10}(M) = 10$ dB in cross-correlation can be achieved when replacing a state-of-the-art CDMA system by a system

25 according to the present invention and performing M=10 integrations therein. Furthermore, it can be seen that the increase of the length of the codes reduces the cross-correlation encountered in all four considered systems. However, when comparing operating points B (-29.9 dB) and C

30 (-28.0 dB), is becomes evident that when using the system according to the present invention with 10 integrations and a code length of N=1000 chips (for the first code, and 999 chips for the second code), the cross-correlation is still

nearly 2 dB lower as in the state-of-the-art system with a
code length of 10000 chips. The present invention, by using
computationally cheap 10-fold integration, thus performs
even better that a system that uses 10 times longer codes,

5   which is of particular relevance when noting that the
computational complexity increases exponentially with the
code length. The additional computational complexity
required to perform the 10-fold integration can be neglected
compared to the computational complexity encountered when

10   increasing the length of the codes by a factor 10.

Fig. 7 depicts a flow chart of the method according to the
present invention. In a first step 700, the delayed SDSS as
transmitted by a plurality of transmitters are received as a

15   superposition. Then the code index is set to i=1 (step 701),
and a replica of the first code is generated in a step 702,
wherein said replica is synchronized with the transmission
instance of the transmitted that uses said first code. In
step 703, the superposition of the received SDSS is

20   correlated with said first code in order to obtain a
complete first CCF or portions thereof. In a step 704,
portions of said complete first CCF or of said portions of
said CCF are selected for combination, and actually combined
in step 705 by means of integration or averaging, yielding a

25   first combined CCF portion. In step 706, the propagation
delay associated with the received SDSS that was spread with
said first code and transmitted by a first transmitter is
determined from the position of the auto-correlation peak
within said first combined CCF portion. Afterwards, in a

30   step 707, the code index i is increased by one, and the
steps 702 to 707 are repeated in order to determine the
delays associated with the received SDSS that was spread
with a second code, and so forth.

Fig. 8 finally is a schematic illustration of a device according to the present invention. Said device comprises a signal reception instance 800, wherein amplification, demodulation (if necessary), pulse-shape matched filtering,

5   equalization and sampling may be performed. The signal reception instance 800 outputs a signal that comprises a couple of received SDSS to a correlator 801. The correlator is fed with code replicas by a code replica generator 802, which is triggered by a clock 803, which in turn is

10   controlled by a synchronization unit 804. The synchronization unit 804 ensures that the clock 803 of the device is synchronized with the universal time that is used by the transmitters. The correlator 801 correlates said signal with a code replica from said code replica generator

15   802 and outputs a CCF or portions thereof to a portion selection unit 805. In this unit, portions of the CCF that are suited for combination are selected or determined and then fed into a portion combination unit 806. In this unit, the actual combination of at least two portions of a CCF is

20   performed by means of averaging or integrating. The resulting combined CCF portion then is handed to a delay detection unit that determines the delay on the delay axis of the combined CCF portion for which an auto-correlation peak is encountered. This delay may be forwarded to a signal

25   processing instance 808, which may as well receive said signal comprising a couple of received SDSS from the signal reception instance 800 and process the actual information of the data symbol stream. Both said information and the delay may be further processed by said signal processing unit for

30   determining the position of the device.

The invention has been described above by means of preferred embodiments. It should be noted that there are alternative ways and variations which are obvious to a skilled person in

the art and can be implemented without deviating from the scope and spirit of the appended claims. In particular, the present invention is by no means restricted to a GNSS such as GPS or Galileo, but is applicable in any CDMA system, for

5   instance in CDMA mobile communication systems. The combination of several portions of the CCF does not necessarily have to be performed in a receiver, but can also be performed in an outside network. The results may then be forwarded to the receiver or to the transmitters to increase

10   the accuracy of the system. It should be noted that the difference between the number of chips of two codes does not necessarily have to be an integer number of chips, also fractional numbers of chips are possible. Furthermore, apart from the fact that phase modulation of the spread data

15   symbol streams may not be mandatory at all, further types of modulation techniques such as frequency or amplitude modulation may be applied.

The invention as presented in this specification allows for

20   a fast and computationally efficient acquisition as compared to prior art systems. The reduction of the cross-correlation is even larger as in a system that uses longer codes. The reduction in coding or spreading gain that results from the reduction of the length of the code by a couple of chips

25   (for instance in the order of some tens, if one length for each satellite is desired) is insignificant as compared to the overall code length, which is of the order 1000 in a GPS system and of the order 10000 in the Galileo system. Frame synchronization between the transmitted frames of several

30   transmitters can be made feasible by choosing the codes so that the frame length in chips equals the least common multiple of all code lengths in the system. Code length reuse is possible, e.g. for satellites that are known to be on opposite sites of the orbit. To allow for a constant data

symbol rate and to combat jamming, periodic changing of the codes is possible. The method according to the present invention breaks the limitation of a communication system that the length of all codes has to be equal and thus

5 contributes to rendering the deployed communication signals similar to noise signals. According to Shannon's information theory, the method according to the present invention thus may contribute to further approach Shannon's channel capacity limit.

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